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1997-98 School Year

Physics 30 Information Bulletin

Diploma Examinations Program

Students First!
Student Evaluation

Alberta
EDUCATION

This document was written primarily for:

Students	✓
Teachers	✓ Physics 30 teachers
Administrators	✓
Parents	
General Audience	
Others	

Distribution: Superintendents of Schools • School Principals and Teachers • The Alberta Teachers' Association • Alberta Education • General Public upon Request

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***Alberta educators** may reproduce this bulletin for **educational purposes**.*

This document can be found on our Web pages. Our Internet address is http://ednet.edc.gov.ab.ca.

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Purpose of the Bulletin

The purpose of this bulletin is to provide students and teachers of Physics 30 with information about the diploma examinations scheduled for the 1997–98 school year.

This bulletin includes descriptions of the Physics 30 diploma examinations, that will be administered in January, April, June, and August of 1998, descriptions of the acceptable standard and the standard of excellence, and subject specific information.

Teachers are encouraged to share the contents of this bulletin with students.

As well, the publication *Students First: A Guide for Students Preparing to Write the Physics 30 Diploma Examination* contains significant information for students.

The document entitled *General Information Bulletin, Diploma Examinations Program* (1997–98) provides administrative information about the diploma examinations for the 1997–98 school year.

This bulletin, the *General Information Bulletin*, and the *Students First* guide are distributed to all senior high school principals and are also available on the Internet at Alberta Education's Web site (http://ednet.edc.gov.ab.ca).

If you have questions or comments about the contents of this bulletin, please contact one of the following persons:

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Important Dates in the 1997–98 School Year

Administration of the Physics 30 Diploma Examination

The diploma examination is designed for a writing time of 2.5 h. Students must be allowed an additional 0.5 h to complete the examination, if required; therefore, examination supervisors must be available for this additional time.

1997–98 Administrations	*Time*
Thursday, January 29, 1998	9:00 –11:30 A.M.
Monday, April 20, 1998	1:00–3:30 P.M.
Friday, June 26, 1998	9:00 –11:30 A.M.
Thursday, August 13, 1998	1:00–3:30 P.M.

Please consult the *General Information Bulletin, Diploma Examinations Program*, for a complete schedule for all subject areas.

Scoring of the Examination

Scoring of the examination will take place shortly after the administration date.

In early September, the Student Evaluation Branch sends superintendents a letter requesting the names of recommended markers. In this letter, dates for scoring the examination will be announced.

Student Evaluation Branch staff will contact recommended markers before each marking session to confirm participation, and the dates and times for marking.

Notes of Interest

Additional Diploma Examination Administrations

Alberta Education is increasing the number of administrations of diploma examinations to accommodate students' examination needs more effectively. For the 1997–98 school year, in addition to the examinations already offered in January, June, and August, the following diploma examinations will be offered in November and April.

Tuesday, November 4, 1997	9:00–11:30 A.M.	English 30 Part A English 33 Part A
Wednesday, November 5, 1997	9:00–11:00 A.M.	English 30 Part B English 33 Part B
	1:00–3:30 P.M.	Chemistry 30
Thursday, November 6, 1997	9:00–11:30 A.M.	Mathematics 30 Mathematics 33
Monday, April 20, 1998	9:00–11:30 A.M.	Social Studies 30 Social Studies 33
	1:00–3:30 P.M.	Physics 30
Tuesday, April 21, 1998	9:00–11:30 A.M.	Biology 30

The November and April examinations will be available only to students who have school marks in the courses and to individuals having mature student status.

All students must preregister to write diploma examinations in November and April; walk-ins will not be allowed. Students should contact their school principal for application forms and for the location of the nearest writing centre. The application deadlines for the November and April writings are October 10, 1997, and March 26, 1998, respectively.

Data Resources for Students

NEW

The Physics 30 diploma examinations contain tear-out data pages and a periodic table. Students should remove the tear-out data pages from the exam booklets at the beginning of the writing session. These pages do not have to be returned with the exam booklets and answer sheets. The data presented are generic for all of the Physics 30 diploma exams provided during a school year; therefore, only some of the data are useful for any particular exam. Minor changes have been made to the data pages. See pages 46 to 48 for samples of the periodic table and new data pages.

Student Use of Scientific Calculators

Examinations are constructed to ensure that the use of particular scientific calculators neither advantages nor disadvantages individual students. Students are expected to provide their own scientific calculators.

Refer to Appendix A for the policy statement on the use of scientific calculators on diploma examinations. Students should be made aware of this policy as early as possible in the school term to ensure they are able to use the scientific calculator of their choice when writing examinations. It is important to clarify with students exactly what they are allowed to have stored in their calculator memories.

Students should also be made aware of the Examination Rules, Grade 12 Diploma Examinations (see the *General Information Bulletin*).

Student Requests for Rescores

Students may request a rescoring of their diploma examinations. Before applying for a rescoring, students should check their *Diploma Examination Results Statement* to find out the distribution of marks. The mark on the machine-scored questions is not likely to change as a result of a rescore, but the written-response mark could change slightly. Students should remember that the rescored mark will be the final mark whether it *increases* or *decreases*.

Students who decide to have an examination rescored must ensure that their application is received before the deadline specified on the results statement. The fee for rescoring each examination is $26.75, which includes GST. If a diploma examination mark is increased by 5% or more as a result of rescoring, the fee is refunded.

Student Requests for Rewriting

Students may rewrite a diploma examination in any regularly scheduled administration. The fee for rewriting each examination is $26.75, which includes GST. Please note that this rewrite fee applies to students repeating the course as well as to those who choose to write the examination. Students must apply to the Student Evaluation Branch by the following dates to be eligible to rewrite the diploma examinations.

Examination Administration	**Rewrite Request Deadline**
January 1998	November 14, 1997
April 1998	March 26, 1998
June 1998	April 29, 1998

(For more details, see the *General Information Bulletin.*)

Children in Need of Protective Services

If a student who is under 18 years of age indicates in his or her writing that he or she is a victim of physical or sexual abuse, the markers are required *by law* to refer the paper to Social Services. Social Services is required to investigate situations that suggest that children might require protection.

Information for Markers

The written-response questions of the Physics 30 Diploma Examinations are marked by Physics 30 teachers selected from those who have been recommended as markers to the Student Evaluation Branch by their superintendents.

Qualifications

To qualify for recommendation, a teacher must have taught the complete Physics 30 course for two or more years (or four semesters) prior to the current school year, be teaching the course in the current school year, and have an Alberta or Northwest Territories Permanent Professional Teaching Certificate.

Dates for Recommendation

Teachers who wish to be recommended as markers for the diploma examinations should contact their superintendents by the following dates.

Diploma Date	**Contact Superintendent by**
January 1998	October 01, 1997
June & August 1998	March 01, 1998

Markers for the November and April examinations will be selected from lists of prospective markers submitted by their respective school superintendents.

Criteria for Selection

More teachers are recommended as markers by superintendents than are required by the Student Evaluation Branch for any one marking session. The following criteria are considered when markers are selected for a particular marking session:

- experience as a marker (experienced markers and first-time markers are included)
- regional representation (by zone, jurisdiction, and school)
- student population (proportional representation)

We particularly need teachers who can mark examinations written in French.

Examination Development

As the need arises for teachers to participate in field testing and item writing, letters are sent to superintendents requesting their nominations. Item writing takes place throughout the year and is a vital component of the diploma exam program. Field testing provides students and teachers with the opportunity to become familiar with the nature of questions they will encounter on future diploma exams. Only teachers who have been nominated by their superintendents are eligible to participate in these activities. Therefore, it is essential that teachers who are interested in these activities should contact their superintendents.

Inservices and Presentations

On a limited basis and subject to budget constraints, Student Evaluation Branch staff may be available to provide inservices or presentations related to diploma examinations or the interpretation of diploma examination results.

Other Important Documents

Guide for Students

A publication written for students called *Students First: A Guide for Students Preparing to Write the Physics 30 Diploma Examination* is available in each senior high school and on Alberta Education's Web site (http://ednet.edc.gov.ab.ca). This publication contains suggestions for exam preparation and exam writing suggestions. The Student Evaluation Branch highly recommends that students and teachers examine this document early in the term to prepare for the Physics 30 Examination. Parents will also find this to be a useful publication.

Examiners' Reports

Following the administration of each January and June diploma examination, the Student Evaluation Branch sends copies of the *Physics 30 Examiners' Report* to all senior high schools in Alberta, and also posts it on Alberta Education's Web site (http://ednet.edc.gov.ab.ca).

The *Examiners' Report* contains

- detailed provincial results
- examiners' comments about student performance on the exam
- a detailed blueprint of the examination by reporting category
- the key and difficulty level for all the questions on the examination
- sample questions accompanied by commentary

The *Examiners' Report* provides important information for teachers who wish to interpret their students' results in relationship to provincial results as an ongoing form of program evaluation.

School and Jurisdiction Reports

School and Jurisdiction Statistical Reports are made available to schools and school jurisdictions after each January and June administration of the diploma examinations. These reports are placed on the Dial-In Facility of the Educational Information Exchange and provide detailed information on how well the students in their school and school district, respectively, did on each of the diploma examinations. Teachers may use these data to reflect on the areas of the program where their students did well and those areas where student performance was poor.

Annual Reports

Each year, the Student Evaluation Branch produces the *Annual Report, Diploma Examinations Program.* This report contains information about the results achieved by all students who wrote diploma examinations in the preceding school year. It also contains special studies on topics of interest.

Each of these special studies will be of interest to teachers who are involved in interpreting the diploma examinations results of their students.

Diploma Examinations Program

Year	Special Studies Topic
1989–90	Comparing Achievement in Various Diploma Examination Courses
1990–91	Different Paths to Success in Diploma Examination Courses
1991–92	Participation Rates in Diploma Examinations Courses
1992–93	Conventions of Language
1993–94	Participation Rates Over Time
1994–95	Grade 12 Enrollment Decline—A Preliminary Assessment
1995–96	Differential Item Performance Between Males and Females on the June 1996 Administration of the Social Studies 30 Diploma Examination

The 1995–96 Annual Report is available on the Internet at Alberta Education's Web site (http://ednet.edc.gov.ab.ca).

General Information Bulletin

Each September, the Student Evaluation Branch sends all senior high school principals and superintendents copies of the *General Information Bulletin, Diploma Examinations Program*, and also posts it on Alberta Education's Web site (http://ednet.edc.gov.ab.ca). This bulletin provides the information, dates, policies, and rules that apply to the administration of all diploma examinations for the school year.

Teachers and students who have questions about such issues as partial writings, word-processor policy details, special provisions for learning and/or physically disabled students writing diploma exams, dates for exam administration, and definitions of mature students, should consult this bulletin.

Previous Examinations

Previous Physics 30 January and June diploma examinations are posted on the Alberta Education's Web site (http://ednet.edc.gov.ab.ca) and are also available for purchase (@$4.00 + G.S.T.) from the

Learning Resources Distributing Centre
12360-142 Street, Edmonton, AB T5L 4X9
Phone: 403-427-5775 (toll-free 310-0000) Fax: 403-422-9750

Teachers and students who are consulting previous exams should use exams administered under the present *Program of Studies*.

Physics 30 Information

Objectives of the Course

Physics 30 is an academic course intended to further students' understanding and application of fundamental concepts and skills. The focus is on understanding the physics principles behind the natural events they experience and the technology they use in their daily lives. The course encourages enthusiasm for the scientific enterprise and develops positive attitudes about physics as an interesting human activity with personal meaning. It develops the knowledge, skills, and attitudes to help students become capable of, and committed to, setting goals, making informed choices, and acting in ways that will improve their own lives and life in their communities.

To develop the required knowledge, skills, and attitudes in Physics 30, it is necessary that students have successfully completed Science 10 and Physics 20.

Standards

Students who achieve an *acceptable standard* but not the standard of excellence in Physics 30 receive a final mark of between 50% and 79% inclusive. They have gained new skills and knowledge in physics but may encounter difficulties if they choose to enroll in post-secondary physics courses. These students are likely able to state and solve problems that can be related quickly to an equation on the data sheet, however, their laboratory skills are limited to following explicit directions and to using laboratory data to verify known physics information. These students are capable of defining and calculating quantities such as one-dimensional momentum; kinetic and potential energies; electric force and the force due to gravity; current, potential difference, and resistance in simple series and parallel circuits; variables in the relationship between the primary and secondary coils of a transformer; speed, wavelength, and frequency of electromagnetic waves; charge-to-mass ratios; and the photoelectric work function. They tend to use item-specific methods in their problem solving and rarely apply the major generalizations of physics such as conservation laws of charge, momentum, and energy. When explaining the connections between science, technology, and society, these students tend to use examples provided from textbooks and have difficulty connecting physics to real-life scenarios beyond the classroom.

Students who achieve a *standard of excellence* in Physics 30 receive a final mark of 80% or higher. They have demonstrated their ability and interest in both mathematics and physics and feel confident about their scientific abilities. These students should encounter little difficulty in post-secondary physics programs and should be encouraged to pursue careers in which they will utilize their talents in physics. Students who achieve the *standard of excellence* show flexibility and creativity when solving problems, and minor changes in problem format do not cause them major difficulties. They seek general methods to solve problems and are not afraid to use conservation laws. They transfer knowledge from one area of physics to another and can express their answers in clear and concise terms. In addition, these students can connect their understanding of physics to real-world situations that include technological applications and implications beyond the classroom setting. In the laboratory, students who achieve the *standard of excellence* can cope with data that are less than perfect or with instructions that are incomplete. These students are capable of defining and calculating quantities such as two-dimensional momentum; current and voltage, using Kirchoff's rules; resistance in series and parallel circuits; the motion of an electric charge in a magnetic field; and variables in the Balmer equation.

Examination Specifications

Each Physics 30 Diploma Examination is constructed as closely as possible to the following specifications. Adjustments in the emphasis may be necessary because the exam includes written-response questions and/or machine-scored questions that cover more than one general learner expectation. Questions on the diploma examination will require students to demonstrate knowledge of physics concepts and apply skills in a context that supports making STS connections.

The design supports the integration of all Physics 30 general learner expectations as outlined in the *Physics 20–30 Program of Studies, Interim, for Senior High Schools*. As a result, the exam is not necessarily arranged sequentially by units but instead is built around scenarios or contexts that support STS connections.

Examination Specifications (continued)

The 1997–98 Physics 30 diploma examinations are constructed to place the following approximate emphases on the Physics 30 Course General Learner Expections.

Knowledge	*Emphasis*
The student can:	
• compare and contrast scalar and vector quantities and fields; apply the concept of field to quantitatively explain, in terms of their source, direction, and intensity, the gravitational, electrical, and magnetic effects on objects and systems	10–20%
• describe quantitatively, analyze, and predict the behaviour and physical interactions of objects that may be in gravitational, electric, and/or magnetic fields, using the principles of kinematics, dynamics, conservation of energy, momentum, and electric charge, in addition to electrostatics and electromagnetism; apply these principles to atomic theory and other applications	35–45%
• explain quantitatively, analyze, and predict the motor/generator effect; describe quantitatively, analyze, and predict the functioning of simple resistive direct current circuits, using Ohm's law and Kirchoff's rules; explain the design, function, and technological applications of simple electric motors, generators, meters, transformers, and other simple electromagnetic devices	10–20%
• explain quantitatively the characteristics and behaviours of electromagnetic waves, and algebraically solve problems using the relationship among speed, wavelength, frequency, and energy, and apply these principles with conservation laws to the atomic theory and other applications	25–35%

Skills	*Emphasis*
The student can:	20–40%
• design, interpret, explain, analyze, and evaluate investigations	
• organize data into tables, graphs, and diagrams and predict relationships	
• interpret, explain, analyze, and evaluate data to infer relationships	
• use appropriate scientific terminology and mathematical language to communicate and explain scientific concepts	

Connections Among Science, Technology, and Society (STS)	*Emphasis*
The student can:	40–60%
• apply cause-and-effect reasoning to formulate relationships in which scientific evidence shapes or refutes a theory, and explain the limitations of science and technology in answering all questions and solving all problems	
• describe and evaluate the design and function of technological solutions to theoretical and practical problems using scientific principles and theories, and relate the ways in which science and technology advance one another	
• evaluate from a variety of perspectives how science and technology are influenced and supported by society, and assess the ability of society to interact responsibly with the environment	
• apply the skills and knowledge acquired in Physics 30 to everyday life and to related and new concepts in post-secondary studies of physics	

Examination Design

The design of the 1997–98 Physics 30 diploma examinations is as follows:

Question Format	*Number of Questions*	*Percent Emphasis*
Multiple Choice	37	53
Numerical Response	12	17
Written Response	2	30

The Physics 30 Diploma Examination uses some linked questions in the multiple-choice and numerical-response sections. Prior to 1995, all multiple-choice and numerical-response questions were developed and scored independently of one another. Now, with the development of more than one question based on the same block of information, a numerical answer from one question may be necessary to complete the calculations in the next question. If students answer the first question incorrectly but use that answer correctly to answer the second question, they will receive full marks for the second question.

To illustrate by example, numerical-response questions 5 and 6 on the January 1997 Physics 30 Diploma Examination are of this type. In numerical-response question 5, the student is required to generate a numerical response for the equivalent resistance for the circuit. Numerical-response question 6 requires the student to then **use the recorded answer** from numerical-response question 5 to calculate the total current. If the student answers numerical-response question 5 incorrectly but then uses **that recorded value** correctly to calculate the answer for numerical-response question 6, the student's response to the question will be marked correct.

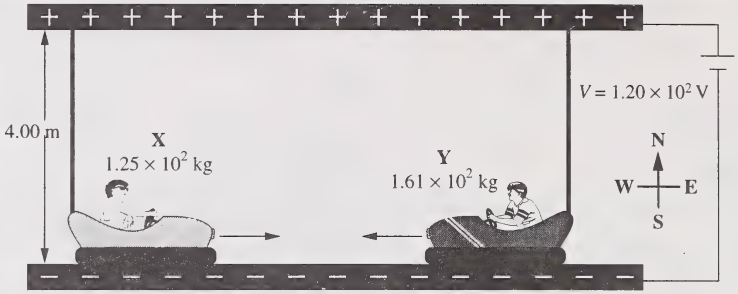
A further example, from the January 1995 Physics 30 diploma examination, linked multiple-choice question 13 and numerical-response question 6. Students could use their recorded answer from multiple-choice question 13 to answer numerical-response question 6 correctly, even though their answer to multiple-choice question 13 may have been incorrect.

These variations in answers can be accommodated by the programming designed for electronic scoring.

Numerical-Response Formats

Several formats for recording numerical-response answers are shown on the following pages. Teachers should ensure that their students become familiar and comfortable with these formats before writing the Physics 30 diploma examinations.

Use the following information to answer the next question.



Bumper cars operate on electricity. The more the accelerator pedal is pressed, the more current flows in the system, and thus the faster the car travels. Car **X** and car **Y** are going to collide head-on. Car **X** is travelling at a constant velocity of 2.25 m/s to the east, and car **Y** is travelling at a constant velocity of 1.30 m/s to the west.

Numerical Response

1. The total mechanical energy of the bumper cars described, expressed in scientific notation, is $\boldsymbol{b} \times 10^{w}$ J. The value of $\boldsymbol{b}$ is __________.
(Round and record your answer to three digits.)

Answer: $\boxed{4}\boxed{.}\boxed{5}\boxed{2}$

Use the following information to answer the next question.

Air pollution can be a serious problem in underground parking garages. The quantity of a particular pollutant in the air can be measured by passing a beam of light through the garage and measuring how much of it is absorbed. The light must have a wavelength that is strongly absorbed by the target pollutant.

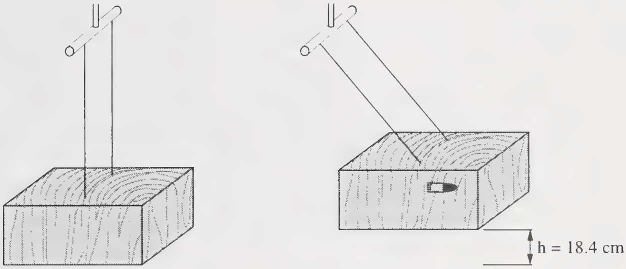
Numerical Response

2. A laser must be designed to supply a wavelength of 164 nm to detect a particular target pollutant. The search for a laser material begins with a list of hydrogen-like atoms/ions. The hydrogen-like atom whose 3-2 transition would emit light at 164 nm would have an E_1 value, expressed in scientific notation, of $-\boldsymbol{a.b} \times 10^{-\boldsymbol{cd}}$ J. The values of $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$, and $\boldsymbol{d}$ are __________.

(Round and record your answer as $\boxed{\boldsymbol{a}}\boxed{\boldsymbol{b}}\boxed{\boldsymbol{c}}\boxed{\boldsymbol{d}}$.)

Answer: $\boxed{8}\boxed{7}\boxed{1}\boxed{8}$

Use the following information to answer the next question.



A ballistic pendulum is a device used to measure the speeds of fast moving objects like bullets. It consists of a wooden block with a mass of 1.00 kg.

A bullet with a mass of 5.00 g is fired from a gun with a barrel that is 74.2 cm long. The gun's mass is 2.45 kg. When the bullet strikes the block, it causes the block to rise to a height of 18.4 cm.

Numerical Response

3. The speed of the bullet just before it strikes the ballistic pendulum, expressed in scientific notation, is $a.bc \times 10^{d}$ m/s.
The values of ***a***, ***b***, ***c***, and ***d*** are __________.

(Round and record your answer as $\boxed{a}\boxed{b}\boxed{c}\boxed{d}$.)

Answer: $\boxed{3}\boxed{8}\boxed{2}\boxed{2}$

Numerical Response

4. Place the following types of EMR in order of increasing energy

1 blue light
2 gamma radiation
3 radio waves
4 ultraviolet radiation

(Record your answer on the answer sheet ☐☐☐☐.)

Answer: $\boxed{3}\boxed{1}\boxed{4}\boxed{2}$

Assessment of STS Connections

Students' understanding of the concepts of science are measured by every question on the examinations. In addition, some questions measure the students' understanding and use of skills associated with scientific inquiry. Some questions have been designed to measure the students' understanding of the connections between science and technology and among science, technology, and society. As a result, many questions measure how well students can apply the skills and knowledge they have acquired in science to everyday life.

Assessment of Communication Skills

Communication skills are assessed most directly in the teacher-scored questions. For the open-response question, the descriptions used in the holistic scoring guides may include criteria for assessing communication skills along with criteria for the other components. Examples of scoring criteria can be found on pages 32 to 34.

The term *communication skills* includes those processes by which information is exchanged through appropriate conventions. These conventions include:

- words, sentences, paragraphs
- graphs, diagrams
- mathematical formulas, mathematical and chemical equations
- significant digits, units of measurement, unit conversion

Conventions that are considered appropriate for a particular response are subject- and question-specific.

"Anaholistic" Scoring

NEW

Each Physics 30 Diploma Examination has two written-response questions, one of which is a closed-response question. Initially, each student's answer to this question will be scored independently by two teachers using an "anaholistic" scoring guide. The two scores are added together for a combined score out of 10. This guide describes the characteristics of the student's answers that correspond to one of six values—0, 1, 2, 3, 4, 5. The descriptor for each level addresses the level of understanding demonstrated by the student's response, the completeness of the response, and the degree to which the student's response communicates their understanding of the physics principles involved in solving the problem. Each scoring guide includes a sample response and marker notes to assist markers in identifying the level of each student response.

For a sample of this type of question and a sample scoring guide, see pages 27 to 30. Students should be made aware of the change in format for these questions.

Holistic Scoring

The other written-response question is an open-response question. Students' answers to the open-response question are scored by teachers using holistic scoring guides. The guides describe the characteristics of students' answers that correspond to one of five values—0, 1, 2, 3, or 4 for the physics content used to solve the problem, and one of four values—0, 1, 2, or 3 for the effective communication of the response. Each student's answer is scored independently by two teachers. The two content scores are added together for a combined total sub-score out of 8, while the two communication scores are averaged for a sub-score out of 3. The two sub-scores are added together for a total out of 11.

A summary of the calculations follows:

Content: Reader 1 Score (X out of 4) + Reader 2 Score (Y out of 4) = Sub-score (X + Y out of 8)

Communication: Reader 1 Score (X out of 3) + Reader 2 Score (Y out of 3) divided by 2 = Sub-score $\left(\frac{X+Y}{2} \text{ out of } 3\right)$

Final score = Content (out of 8) + Communication (out of 3)

If the scores for content obtained by the two independent readings vary by 2 or more, the scores are classified as *discrepant*. Student responses that have *discrepant* scores are read by a third reader. The third reader must assign a score that is equal to one of the scores of the first two readers or is between these scores.

A summary of the calculation for a discrepant paper follows:

Third Reader:
    Content: Reader 1 assigned a score of 1 out of 4 marks
                Reader 2 assigned a score of 3 out of 4 marks
    Reader 3 must assign a 1, 2, or 3. This score will be doubled for a total out of 8.

For an example of this type of question, sample answers, and holistic scoring guides, see pages 31 to 39. Another example of this type of question can be found on the 1997 June Diploma Examination, written-response question 1.

Changes for 1997–98

NEW

For all Physics 30 diploma examinations beginning in the 1997–98 school year, each of the written-response questions will be equally weighted at 15% of the total exam. The total for the written-response component will remain at 30% of the total examination, and the total for the machine-score component will remain at 70% of the total examination.

There have been some minor adjustments made to the data sheets. A copy of the new data sheets is included on pages 46 to 48.

Field Test Results

NEW

Field test results for the 1996–97 school year indicate that students' ability to communicate their ideas in written work has improved considerably. Questions involving mechanical energy, Lenz's Law, vector solutions to two-dimensional problems, and risk/benefit analyses continue to indicate that students have difficulties in these areas.

Comments Relating to Graphing and Suitable Averaging Procedures

Graphing Connections

Students should be proficient at constructing graphs for scientific data. Some general guidelines for graphing scientific data follow.

1. The manipulated variable should be plotted on the horizontal axis, and the responding variable should be plotted on the vertical axis.

2. The scale for each axis should be set so that it spreads out the measured data as much as possible. Scales should be easy to read and evenly divided. All axes must be labelled with the variable used and complete units, including any power of 10.

3. The graph should have a clear title. This is usually stated as "Responding vs. Manipulated" variable, with a further descriptor to help identify the data.

4. Each data point should be plotted. A small circle may be drawn around each plotted point to indicate that it is a data point. Best fit lines or curves may not include all points due to experimental error. Best fit lines or curves do not necessarily include the origin.

Suitable Averaging Procedures

When asked to use an averaging technique to analyze a graph, students should be using slope or another suitable averaging method.

Finding Slope

Students should be made aware that finding slope is the most suitable averaging procedure we have. Therefore, when they are asked to use an averaging procedure to analyze data, slope should be their first choice.

Generally, students understand that slope is defined as the rise/run. Some general guidelines for finding slope follow.

1. Always use on-line points that can be read easily.
2. Data points should not be used in a slope calculation.
3. The triangle should always be large, so as to minimize calculation errors.
4. The origin should not be assumed to be a suitable point.
5. Units and powers of ten should be included in the calculation.
6. Significant digits for the slope are determined by the precision of the observations recorded in the data table.

Other Averaging Procedures

If slope is not used as an averaging technique, students should then use the average of the desired values, or the weighted mean (not the average of the manipulated and responding variables). Care must be taken when using these averaging methods because the origin or another non-permissible value may be given as data. An example illustrating both a slope calculation and another suitable averaging procedure, and their uses, follows.

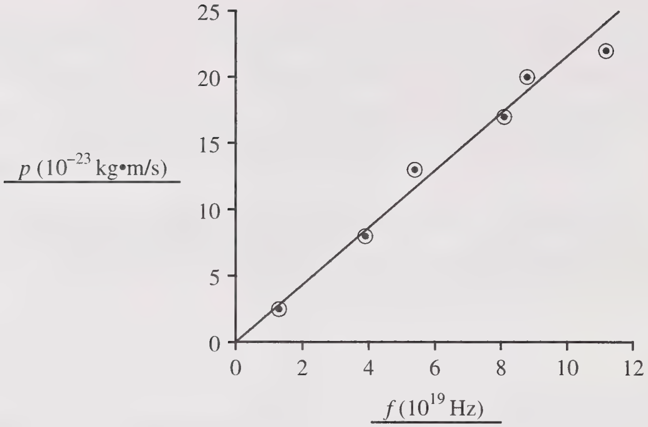
Example of Suitable Averaging Procedures

Independent measurements were made of the momentum *p* and of the frequency *f* of X-rays. The results are summarized in the table:

p (10^{-23} kg•m/s)	f (10^{19} Hz)
2.5	1.3
8.0	3.9
13.0	5.4
17.0	8.1
20.0	8.8
22.0	11.2

a. From the data in the table, plot a graph of momentum as a function of frequency, placing frequency on the horizontal axis.

Momentum as a Function of Frequency



b. Use the slope of the graph or some other suitable averaging procedure to determine the **best** estimate of Planck's constant h.

Slope Method

$$\text{slope} = \Delta p/\Delta f$$

$$= \frac{(19 - 6.0)(10^{-23}\ \text{kg•m/s})}{(8.8 - 2.8)(10^{19}\ \text{Hz})}$$

$$\text{slope} = 2.17 \times 10^{-42}\ \text{kg•m}$$

Here, the slope is not Planck's constant but must be used to find h.

$$p = hf/c$$

$$\text{since slope} = \frac{\Delta p}{\Delta f}$$

$$h = c(\text{slope})$$

$$= (3.00 \times 10^{8}\ \text{m/s})(2.17 \times 10^{-42}\ \text{kg•m})$$

$$h = 6.5 \times 10^{-34}\ \text{J•s}$$

For the slope calculation, all six guidelines were followed.

Averaging Method: using data points

$$h = pc/f$$

$$h_1 = (2.5 \times 10^{-23}\ \text{kg•m/s})(3.00 \times 10^{8}\ \text{m/s})/(1.3 \times 10^{19}\ \text{Hz})$$

$$= 5.8 \times 10^{-34}\ \text{J•s}$$

$$h_2 = 6.2 \times 10^{-34}\ \text{J•s}$$

$$h_3 = 7.2 \times 10^{-34}\ \text{J•s}$$

$$h_4 = 6.3 \times 10^{-34}\ \text{J•s}$$

$$h_5 = 6.8 \times 10^{-34}\ \text{J•s}$$

$$h_6 = 5.9 \times 10^{-34}\ \text{J•s}$$

$$h_{(\text{ave})} = \frac{h_1 + h_2 + h_3 + h_4 + h_5 + h_6}{6}$$

$$h_{(\text{ave})} = 6.4 \times 10^{-34}\ \text{J•s}$$

In finding the average value for Planck's constant, all six values were calculated. These values were then averaged. This method may yield different results because of the inclusion of points that have large experimental errors. Note that the averaging equation was explicitly stated. However, it is acceptable to state the averaging equation implicitly.

In this particular problem, the following method yields a reasonable value for Planck's constant but is generally considered unacceptable.

$$p_{(\text{ave})} = \frac{\Sigma p}{6} = 13.8 \times 10^{-23}\ \text{kg•m/s}$$

$$f_{(\text{ave})} = \frac{\Sigma f}{6} = 6.45 \times 10^{19}\ \text{Hz}$$

$$f_{(\text{ave})} = \frac{p_{(\text{ave})} \bullet c}{f_{(\text{ave})}} = 6.4 \times 10^{-34}\ \text{J•s}$$

This method gives the correct answer **only** because the graph goes through the origin; as a general practice, the origin should **not** be used. Often, when experimental errors are present, graphs that are meant to go through the origin do not go through it. Thus, the use of this particular procedure involves making an unwarranted assumption.

Comments Relating to Real and Fictitious Forces

NEW

The following information was provided by **Dr. H. Laue, Department of Physics and Astronomy, University of Calgary**, in response to concerns raised about students' misconceptions primarily in the area of circular motion. It contain tips on

- the nature of forces
- Newton's Second Law
- centripetal force
- fictitious forces and non-inertial frames of reference

The Nature of Forces

Ordinarily, when one says "a force is acting on a body," one is talking about a **real** force. Real forces are the result of interactions between **two** objects. In order for a force to be acting on an object A, there must be a second object B present that is interacting with object A. An object A cannot exert a (net) force on itself. It can be said that **object B exerts a force on object A**.

Forces are either contact or action-at-a-distance forces.

1. **Contact forces** These arise when two objects are in contact; for example,
   - a hand pushing against a chair: the hand is exerting a force on the chair
   - a car towing a trailer: the car is exerting a force on the trailer
   - a hockey puck sliding over the ice: the ice is exerting a small force of friction on the hockey puck

2. **Action-at-a-distance forces** These arise when two objects interact that are not in contact, but separated; for example,
   - the magnetic force of attraction exerted by a magnet on a paper clip separated from it by a few centimetres
   - the electrostatic force of repulsion between the two separated leaves of an electroscope carrying electric charges of equal sign
   - the gravitational force of attraction between the earth and the moon

Comments The distinction between contact and action-at-a-distance forces is one of scale. Fundamentally, contact forces are due to interatomic forces, which are electromagnetic in nature and therefore action-at-a-distance forces. However, the distances are so small in this case that on the macroscopic level these forces appear as new kinds of forces and are given special names such as friction and normal forces. The examples above do not contain a separate item called “centripetal force.”

What makes a force acting on an object **real** is the presence of a second object causing the force. In contrast, **fictitious** forces, e.g., the centrifugal force, arise **without** a second object. They arise only in non-inertial frames of reference and **never** enter into the description of a motion that is viewed from an inertial frame.

The curriculum requires only a treatment of physics with inertial frames of reference. In such frames, there are no **fictitious** forces and the treatment of such forces can be avoided. However, examples of fictitious forces sometimes get mentioned, e.g., the **centrifugal** (centre-fleeing) force. The centrifugal force **never** enters the description of any physical process as long as one sticks to inertial frames of reference.

Newton’s Second Law of Motion

The (vector) sum of all forces, i.e., the **net force** acting on an object, is equal to the product of the object’s mass and the object’s acceleration. In symbols,

$$\boldsymbol{F}_{\text{net}} = m\boldsymbol{a}. \tag{1}$$

Comment On the left side of this equation, we enter all **real** forces acting on the object, and nothing else. The right side is **not** a force, but simply the product of the mass and the acceleration of the object on which the forces on the left side are acting. It is remarkable that these two very different kinds of things can be related: (a) the forces acting on an object and (b) the mass and acceleration of that object. Equation (1) is an equation, not an identity. Thus, it is incorrect to refer to ***ma*** as a force. The product ***ma*** involves attributes of only a **single** object, the object's mass and acceleration, whereas force expressions always involve the attributes of **two** objects.

Centripetal force

A "**centripetal force**" is any force whose direction is toward the centre of a circle. It is not a separate kind of force. Any of the forces mentioned above, as examples of real forces, could be a centripetal force. The term "centripetal force" is problematic because it can leave the learner with the impression that in circular motion one deals with a **new** kind of force $\boldsymbol{F}_{\mathbf{c}}$, the centripetal force, whose direction is toward the centre of the circle and whose magnitude is equal to mv^2/r.

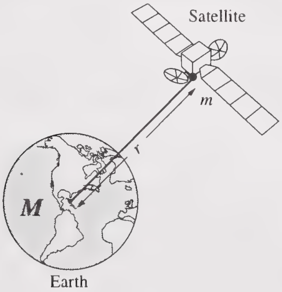
The concept of "centripetal force" is commonly used when an object is performing uniform circular motion because, in this case, the net force is directed toward the centre of the circle. At the same time, the concept of the net force and the role of Newton's Second Law are often de-emphasized. In doing so, one misses an excellent opportunity to demonstrate how Newton's Second Law combined with kinematics can explain all motions.

The term centripetal force has been deleted from the Physics 20-30 Program of Studies, issued by Alberta Education June 1995, in favour of an increased emphasis on Newton's Second Law. This deletion recognizes that the term "centripetal (centre-seeking) force" can be misleading. See the description of Unit 2 of the Physics 20 Curriculum, Circular Motion and Gravitation, p.19–20, of the Program of Studies.

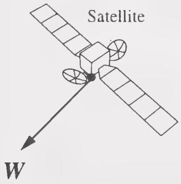
The following example on circular motion will compare a solution that refers to Newton's Second Law and kinematics to a solution that uses the "centripetal-force language."

Example

An artificial satellite of mass m is moving with constant speed v around the Earth in a circular orbit of radius r. The Earth's mass is equal to M, and the universal gravitational constant is equal to G. What is the speed of the satellite?



(a)



(b)

Solution 1

Newton's Second Law and Kinematics Diagram (a) shows the Earth and the satellite. Diagram (b) is the free-body diagram for the satellite. As diagram (b) shows, there is only one force acting on the satellite, the gravitational force $\vec{W}$ exerted by the earth on the satellite. According to Newton's law of universal gravitation, the magnitude W of this force is equal to

$$W = \frac{GMm}{r^2}. \tag{2}$$

The expression for $\vec{W}$ in equation (2) is called a **force expression**. Since the gravitational force is the only force acting on the satellite, it is equal to the net force. Taking magnitudes of both sides of the Newton's Second Law equation (1) and substituting expression (2) on the left side of the resulting equation yields

$$\frac{GMm}{r^2} = ma \Rightarrow \frac{GM}{r^2} = a. \tag{3}$$

One knows from kinematics that the acceleration of an object moving with constant speed in a circle has a magnitude

$$a = \frac{v^2}{r}. \tag{4}$$

Substituting expression (4) into equation (3) gives an equation for the speed v,

$$\frac{GM}{r^2} = \frac{v^2}{r}, \tag{5}$$

which has the solution

$$v = \sqrt{\frac{GM}{r}}. \tag{6}$$

The mass m of the satellite has dropped out. The speed v does not depend on it.

Solution 2

"Centripetal-force language" The following passage is not taken from any source, but is invented here to give the flavour of the argument.

For an object in uniform circular motion, there must be a centripetal force F_c acting on the object equal to

$$F_c = \frac{mv^2}{r}. \tag{7}$$

The gravitational force W in equation (2) supplies the centripetal force in this case. Thus, equating W to F_c, we obtain

$$\frac{GMm}{r^2} = \frac{mv^2}{r} \tag{8}$$

Then, result (6) follows from equation (8) as before.

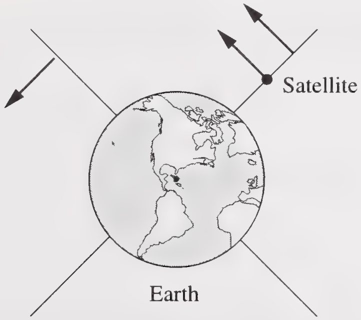
Comments First of all, solution 2 is not incorrect if properly interpreted. However, the solution misleads many students who carry away from it the idea that in a uniform circular motion problem there is something called centripetal force, whose magnitude is **identical** with mv^2/r, and that whatever force is acting must be equal in magnitude to this centripetal force. Thus, in the case of the second solution, many students learn that $W = F_c$, where F_c is just a shorthand for mv^2/r. They fail to appreciate that in this case it is the gravitational force that is causing the circular motion and the centripetal acceleration. Many students do not grasp the idea that Newton's Second Law is an equation relating the sum of all forces acting on an object to the product of the object's mass and acceleration, and that the acceleration is caused by the forces but is not part of the forces.

For these reasons, the curriculum now specifies that the appropriate language involving Newton's Second Law be used when dealing with circular motion problems, as illustrated in solution 1. (See Physics 20-30 Program of Studies, June 1995, p. 20.) This way, all students can learn to appreciate the significance of this law and those students who go on to more advanced studies will have a sound foundation.

Fictitious Forces and Non-Inertial Frames of Reference

Note Fictitious forces are beyond the scope of the Physics 20 – 30 Program of Studies.

There is a third solution to the above example. It uses the concept of **centrifugal** force. This solution justifies equation (8) by saying that the gravitational force acting on the satellite must be balanced by the fictitious centrifugal force acting on the satellite. The two forces are of equal magnitude, but in opposite directions and thus add up to a zero net force. As a result, the satellite can remain at a constant distance from the Earth.



This argument is correct in the reference frame that is rotating with the satellite so that the satellite is at rest in this frame. The diagram above shows the satellite (black dot) moving around the Earth in the plane of the paper and a pair of axes rotating with the satellite so that the satellite always remains on one of the axes. The frame rotating with the satellite around an axis perpendicular to the paper is a non-inertial reference frame.

Newton's Second Law is not valid in non-inertial reference frames. The example of the satellite illustrates why. Newton's Second Law would imply that the net real force acting on the satellite, which is the gravitational force in this case, would cause the satellite to accelerate. However, the satellite does **not** accelerate relative to the rotating axes. It remains at rest relative to these axes. Therefore, Newton's Second Law does not hold relative to the rotating frame.

One can "fix this problem" by inventing **fictitious** forces so that it looks as if Newton's Second Law were true in the rotating frame. In uniformly rotating reference frames, one needs two fictitious forces to fix things. One of them is the **Coriolis** force. This force depends on the object's velocity relative to the rotating frame and is equal to zero when this velocity is zero. This force is not needed in the example because the satellite is not moving relative to the rotating frame. The other fictitious force is the **centrifugal** force. It is directed radially away from the rotation axis and has a magnitude equal to $mr\omega^2$, where ω is equal to the angular speed of rotation of the rotating frame. Note that the magnitude of the centrifugal force depends on ω and is **independent** of the speed of the object on which the force is acting. This is often overlooked. In general, the magnitude of the centrifugal force is not equal to mv^2/r, where v is the speed of the particle in the non-rotating frame. The force is an aspect of the reference frame and therefore depends on a parameter, ω, that defines the motion of this frame. At the same time, there is nothing in the expression $mr\omega^2$ that refers to a second object, because there is none in the case of a fictitious force.

For the special case of an object at rest in the rotating frame at a distance r from the axis of rotation of the frame, it is true that $v = r\omega$, and therefore $mr\omega^2 = \frac{m(r\omega)^2}{r} = \frac{mv^2}{r}$. Thus, in this **special** case, the magnitude of the centrifugal force in the rotating frame can be expressed in terms of v by mv^2/r.

Fictitious forces are artifacts of non-inertial frames. They exist only because one is referring a motion to such a frame. No second object is present that would cause a fictitious force to exist. When a motion is viewed from a non-inertial frame, it **looks** as if there were fictitious forces acting on the moving object because the object's acceleration in this frame cannot be accounted for by the real forces that are present.

Non-inertial reference frames These are frames that are accelerated relative to inertial frames. Inertial frames are frames in which Newton's First Law of Motion is true; i.e., frames in which an object will remain at rest or move with constant speed in a straight line as long as no **real** forces are acting on it. The Earth's surface defines an inertial frame to a good approximation. This is not a true inertial frame, however, for several reasons; e.g., because the Earth is rotating slowly around its axis, once every day.

Sample Anaholistic Question and Scoring Guide

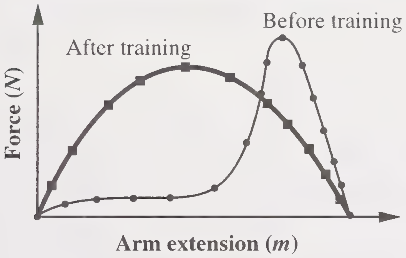
Written Response

The biomechanics lab at a local university runs a series of tests on potential Olympic athletes. The intent is to develop an appropriate training program for each athlete. The areas of study focus on energy output, impulse, force, and performance techniques.

A shot putter is given an exercise to put (throw) the shot horizontally using arm motion only. The hand at the point of release is 1.50 m above the ground. The shot lands 4.43 m horizontally from the hand. The mass of the shot is 7.26 kg.

The athlete's performance was measured before and after a session with a coach focusing on techniques to improve performance. The following graph reflects those measurements.

An Athlete's Performance



- Calculate the speed the shot leaves the hand.

- Using the speed calculated and any other given information, find the total mechanical energy of the shot immediately on release.
  (If you were unable to calculate the speed of the shot, use the hypothetical value $v = 10.2$ m/s)

- Find the impulse and average force acting on the shot if the action of pushing on the shot takes 1.87×10^{-1} s.
  (If you were unable to calculate the speed of the shot, use the hypothetical value $v = 10.2$ m/s)

- Explain how the athlete's performance has improved with training. Justify your answer using information given in the problem and physics principles.

Clearly communicate your understanding of the physics principles that you are using to solve this question. You may communicate this understanding mathematically, graphically, and/or with written statements.

Sample Solution

- Speed of the shot as it leaves the hand.

$$d = v_i t + \frac{1}{2}at^2 : v_i = 0 \text{ in the vertical direction}$$

$$t = \sqrt{2d/a}$$

$$= \sqrt{2(1.5\text{ m})/(9.81\text{ m/s}^2)}$$

$$t = 0.553\text{ s}$$

$$d = v_i t + \frac{1}{2}at^2 : a = 0 \text{ in the horizontal direction}$$

$$= (4.43\text{ m})/(0.553\text{ s})$$

$$v = 8.01\text{ m/s}$$

- Mechanical energy of the shot on release. The total mechanical energy is the sum of the kinetic energy and the potential energy. Total energy is conserved.

$$E_T = E_k + E_p$$

$$= \frac{1}{2}mv^2 + mgh$$

$$= \frac{1}{2}(7.26\text{ kg})(8.01\text{ m/s})^2 + (7.26\text{ kg})(9.81\text{ m/s}^2)(1.50\text{ m})$$

$$= 2.329 \times 10^2\text{ J} + 1.068 \times 10^2\text{ J}$$

$$E_T = 3.40 \times 10^2\text{ J} \text{ (if } v = 10.2\text{ m/s was used, } E_T = 4.85 \times 10^2\text{ J)}$$

- Impulse produced on the shot by the shot putter.

$$J = m\Delta v = F\Delta t$$

$$= (7.26\text{ kg})(8.01\text{ m/s})$$

$$J = 5.82 \times 10^1\text{ kg•m/s} = 58.2\text{ kg•m/s}$$

$$\text{(if } v = 10.2\text{ m/s was used, } J = 74.1\text{ kg•m/s)}$$

Average force exerted by the shot putter.

$$F\Delta t = m\Delta v$$

$$F = m\Delta v/\Delta t$$

$$= (5.82 \times 10^1\text{ kg•m/s})/(1.87 \times 10^{-1}\text{ s})$$

$$F = 3.11 \times 10^2\text{ N} \text{ (if } v = 10.2\text{ m/s was used, } F = 3.96 \times 10^2\text{ N)}$$

- Explain how the athlete's performance has improved with training. Justify your answer using information given in the problem and physics principles.

The area under a force–distance graph is equal to the work done. After training, the work that the athlete does on the shot is greater, since the area under the graph is greater.

An increase in the work done on the shot will result in an increase in the kinetic energy imparted to the shot. The shot's speed will increase, and therefore the distance it travels will increase.

Anaholistic Scoring Guide

Biomechanics Lab

4 Major Concepts: Speed of the shot, Mechanical Energy, Force and Impulse, and Work and Energy

Level	Criteria
NR	No response is given.
0	The response • identifies an area of physics that does not apply to the problem • uses inappropriate formulas, diagrams, explanations, and/or graphing techniques
1	The response • attempts at least two of the major concepts **or** uses an appropriate method that reflects a good understanding of one of the major concepts • errors in the formulas, diagrams, explanations, and/or graphs are present, and the answer is not consistent with calculated and/or graphed results
2	The response • uses an appropriate method that reflects a basic understanding of three of the four major concepts **or** a good understanding of two of the major concepts • has formulas, diagrams, and/or graphs that are implicitly correct, but the applications of these are not made to the final solution, **or** errors in application of equations are present, but the answer is consistent with calculated results
Marker Notes	This student is likely able to correctly calculate impulse, average force, and mechanical energy using the hypothetical value.
3	The response • uses an appropriate method that reflects a basic understanding of all four of the major concepts **or** a good understanding of three of the major concepts • uses an appropriate method that reflects an excellent understanding of two of the major concepts **and** a basic understanding of one of the two remaining concepts • formulas and/or diagrams may be implicit, but are applied correctly; errors in calculations and/or substitutions are present, that hinder the understanding of the physics content • explanations are correct but lack detail • graphs are correct, but slope calculations probably use data points instead of line points • has a major omission or inconsistency
Marker Notes	This student likely calculates speed incorrectly and uses that calculated value.
4	The response • uses an appropriate method that reflects a good understanding of all of the major concepts **or** an excellent understanding of three of the major concepts • most formulas and/or diagrams are explicit and are applied correctly; minor errors in calculations and/or substitutions are present, but do not hinder the understanding of the physics content • explanations are correct and detailed • graphs are correct; slope calculations may use data points instead of line points • has minor omissions or inconsistencies • may have an error in units, significant digits, rounding or graphing
Marker Notes	The student may not address either the issue of the change in area of the force-distance graph (work done) with training **or** the calculation of the speed of the shot.
5	The response • uses an appropriate method that reflects an excellent understanding of all the major concepts • provides a complete description of the method used and shows a complete solution to the problem • explicitly states formulas • may have a minor error or inconsistency present, but it does not hinder the understanding of the physics content • diagrams are appropriate, correct and complete • slope calculations must use line points • may have an error in significant digits or rounding

Anaholistic Scoring Guide

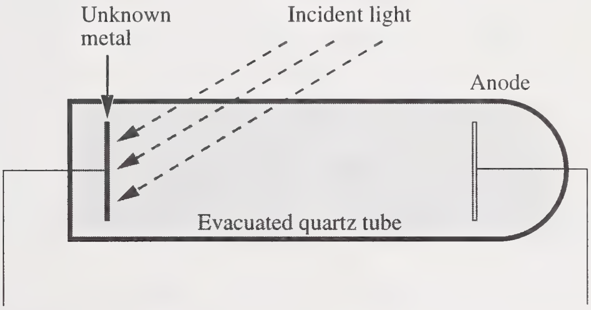
Major Concepts **Generic**	
Level	**Criteria**
NR	No response is given.
0	The response: • identifies an area of physics that does not apply to the problem • uses inappropriate formulas, diagrams, explanations, and/or graphing techniques
1	The response: • attempts at least two of the major concepts **or** uses an appropriate method that reflects a good understanding of one of the major concepts • errors in the formulas, diagrams, explanations, and/or graphs are present, and the answer is not consistent with calculated and/or graphed results
2	The response: • uses an appropriate method that reflects a basic understanding of three of the four major concepts **or** a good understanding of two of the major concepts • has formulas, diagrams, and/or graphs that are implicitly correct, but the applications of these are not made to the final solution, **or** errors in application of equations are present, but the answer is consistent with calculated results
3	The response: • uses an appropriate method that reflects a basic understanding of all four of the major concepts **or** a good understanding of three of the major concepts • uses an appropriate method that reflects an excellent understanding of two of the major concepts **and** a basic understanding of one of the two remaining concepts • formulas and/or diagrams may be implicit, but are applied correctly; errors in calculations and/or substitutions are present that hinder the understanding of the physics content • explanations are correct but lack detail • graphs are correct, but slope calculations probably use data points instead of line points • has a major omission or inconsistency
4	The response: • uses an appropriate method that reflects a good understanding of all of the major concepts **or** an excellent understanding of three of the major concepts • most formulas and/or diagrams are explicit and are applied correctly; minor errors in calculations and/or substitutions are present, but do not hinder the understanding of the physics content • explanations are correct and detailed • graphs are correct; slope calculations may use data points instead of line points • has minor omissions or inconsistencies • may have an error in units, significant digits, rounding, or graphing
5	The response: • uses an appropriate method that reflects an excellent understanding of all the major concepts • provides a complete description of the method used and shows a complete solution to the problem • explicitly states formulas • may have a minor error or inconsistency present, but it does not hinder the understanding of the physics content • diagrams are appropriate, correct, and complete • slope calculations must use line points • may have an error in significant digits or rounding

Sample Holistic Question, Scoring Guide, and Sample Answers

Written-Response
Question 2, January 1996

Use the following information to answer the next question.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes is shown below.



Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

2. Design an experiment using the photoelectric effect to distinguish between Metal X and Metal Y. Your experimental design must contain:

- Statement of the purpose of the experiment
- List of the equipment needed
- A complete labelled diagram (above) of all the equipment necessary
- Procedure
- Measurements to be made and recorded, and any tables necessary
- Description of the analysis to be done
- An explanation using either the calculation or the derived algebraic equation showing how it will be used to distinguish between Metal X and Metal Y.

Note: A maximum of 8 marks will be awarded for the physics used in your design. A maximum of 3 marks will be awarded for the effective communication of your response.

Written-Response Question 2—Holistic Scoring Guide
Reporting Category: Physics COMMUNICATION

When marking COMMUNICATION, the marker should consider how effectively the response *describes the experimental design used to distinguish between Metal X and Metal Y.*

Score	Criteria
3	The response: • is complete, well organized, and clear and relevant to the topic • describes a detailed experimental design in a logical manner demonstrating consistency of thought • uses physics vocabulary appropriately, and a precise, explicit relationship exists between the experiment and the diagram(s) • explicitly states formulas, equations, or relationships used to distinguish between Metal X and Metal Y • may have a minor error or omission, but this does not hinder the communication of the design
2	The response: • is somewhat complete and organized; however, it lacks clarity • describes an experimental design, but details are general and/or sometimes lacking, leaving it somewhat open to interpretation • uses physics vocabulary; however, this is sometimes misused, and an implicit relationship exists between the experiment and the diagram(s) • includes formulas, equations, or relationships that may be inferred when used to distinguish between Metal X and Metal Y • likely has errors or omissions that may hinder the communication of the design
1	The response: • is incomplete, unorganized, and somewhat unclear • describes an experimental design but provides little or no detail • uses physics vocabulary; however, this is often misused, and there is a weak relationship between the experiment and the diagram(s) • includes formulas, equations, or relationships that may be inferred by analyzing the explanation • has errors and/or omissions that hinder the communication of the design
0	The response: • is not complete, organized, or clear • does not describe a design • uses little or no physics vocabulary and there is no relationship between the explanation (if present) and the diagram (if present) • may state a formula, equation, or relationship but it does not contribute to the design • is confusing and/or frustrating to the reader • has very little written
NR	No response is given.

Written-Response Question 2—Holistic Scoring Guide
Reporting Category: Physics CONTENT

When marking CONTENT, the marker should consider how effectively the response uses physics concepts, knowledge, and skills in the *design of the experiment using the photoelectric effect to distinguish between Metal X and Metal Y.*	
Score	**Criteria**
4	The response: • shows the design of an experiment that reflects a *thorough understanding* of the photoelectric effect by *correctly distinguishing* between Metal X and Metal Y. • contains an *accurate statement* of the purpose, a *complete list* of the equipment needed, and a *procedure that supports* the experimental design • *identifies measurements* to be made and *refers to any tables* necessary • *accurately describes* the analysis to be done in order to distinguish between Metal X and Metal Y • *may contain minor errors* in the equations and/or concepts; however, these *do not hinder the understanding* of the physics content • has *no major inconsistencies*
3	The response: • shows the design of an experiment that reflects a *good understanding* of the photoelectric effect but that may produce *difficulty distinguishing* between Metal X and Metal Y • contains a *correct statement* of the purpose, a list of *most of the equipment* needed, and a *procedure that provides support* for the experimental design • identifies *most measurements* to be made and *likely refers* to any tables necessary • *describes the analysis* to be done in order to distinguish between Metal X and Metal Y • *may contain minor errors* in equations and/or concepts *that hinder* the understanding of the physics content • *may have several minor inconsistencies* or perhaps *one major inconsistency* (omits accurate description of the analysis) although there is little doubt that there is good understanding
2	The response: • shows the design of an experiment that reflects a *partial understanding* of the photoelectric effect and that *most likely does not distinguish* between Metal X and Metal Y • *contains a statement* of the purpose, a list of *some of the equipment* needed, and a *procedure that provides support* for the experimental design • *identifies few measurements* to be made and *likely fails to refer* to any tables • describes *some of the analysis* to be done in order to distinguish between Metal X and Metal Y • *contains minor errors* in equations and/or concepts that *hinder the understanding* of the physics content • has *inconsistencies or a major omission* that indicates a partial understanding

1	The response: • shows the design of an experiment that reflects a *poor understanding* of the photoelectric effect and *does not distinguish* between Metal X and Metal Y; may recognize some aspects of the photoelectric effect • *may contain a statement* of the purpose, a list of *equipment*, and a *procedure* that *may or may not support* the experimental design • *may identify measurements* and/or reference tables, however, their use is likely *inappropriate and/or incorrect* • *describes little or no analysis* to be done in order to distinguish between Metal X and Metal Y • contains major errors in equations and/or concepts, indicating poor understanding of the physics content • has *minor and major inconsistencies and/or omissions*
0	The response: • shows the design, if present, of an experiment that reflects *little or no understanding* of the photoelectric effect • provides *no statement of purpose*, *no list of equipment*, and *no procedure* • provides *no measurements* or *analysis* • has *major omissions*
NR	No response provided

Student Sample One

Communication Score—2

Rationale: The response is well organized and includes all of the required elements; however, it is unclear from the procedure given exactly what measurements are to be made, and once made, whether those measurements will support the analysis; i.e., the analysis requires stopping voltage to be measured, but this is not specified in the procedure.

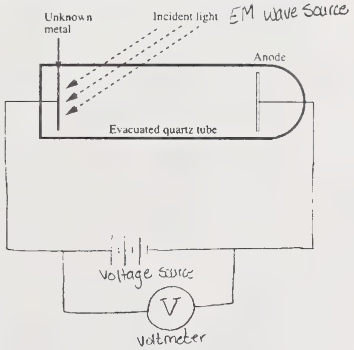
Content Score—4

Rationale: The response addresses all of the required elements. The explanation reflects a thorough understanding of the photoelectric effect. Although metal X and metal Y are not identified, the process by which they could be is outlined. Use of all formulas is correct.

Written Response – 11 marks

Use the following information to answer written-response question 2.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes are shown below.



Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

The purpose of this experiment is to use a variable voltage source and a variable frequency electromagnetic wave source in order to discover the threshold frequencies of the metals. Since each metal has a different threshold frequency we will then be able to identify the metals.

MATERIALS

1. Variable frequency electromagnetic wave source.
2. variable voltage source
3. volt meter
4. unknown metals (x & Y)
5. reference tables giving threshold frequencies.

PROCEDURE

1. Set frequency of EM wave source
2. Set and measure voltage
3. Raise voltage until electron movement stops
4. Repeat for other metal
5. It is helpful to repeat the procedure for better accuracy.
6. Record results.

RESULTS Metal x:

Trial	Stopping V(v)	Ekmax(J)	Frequency(Hz)	fo(Hz)
1 ⋮				
AVE				

Metal Y:

Trial	Stopping V(v)	Ekmax(J)	Freq.(Hz)	fo (Hz)
1 ⋮				
Ave.				

ANALYSIS

formulas:

$$E_{k\,max} = q \cdot V_{stop}$$
$$= h(f - f_0)$$
$$\therefore qV_{stop} = h(f - f_0)$$
$$f_0 = \frac{qV_{stop}}{h} + f$$

$q = 1.60 \times 10^{-19}$ C

$h = 6.63 \times 10^{-34}$ Js

Use these formulas and constants in order to find the threshold frequency of each metal.

Content	4 × 2 =	8
Communication		2
		10/11

Student Sample Two

Communication Score—3

Rationale: The response is well organized, relevant, and clear. The response specifies a detailed procedure that demonstrates a logical, consistent approach. There is a precise relationship between the experiment and the diagram, and the formulas necessary to distinguish between metal X and metal Y are explicitly stated.

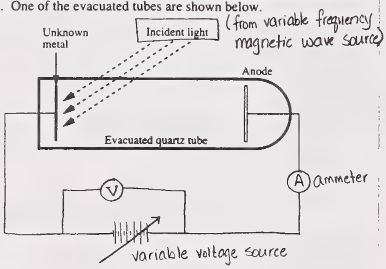
Content Score—3

Rationale: The response addresses all of the required elements and reflects a good understanding of the photoelectric effect. Although the concept of threshold frequency is clearly outlined in the explanation, the procedure given will not produce the measurements needed. As evidenced by the discussion and diagram, the student clearly does not recognize that the stopping potential of the photoelectrons is needed to compute the kinetic energy of those photoelectrons, and consequently, the threshold frequency of metals X and Y. Therefore, the procedure will be unlikely to distinguish between metal X and metal Y.

Written Response – 11 marks

Use the following information to answer written-response question 2.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes are shown below.



f_0 for u.v. light higher

f_0 for visible light lower.

Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

Analysis: Because we know that ultraviolet light has a higher frequency than visible light and that both EMR are next to each other on the light spectrum, we can conclude that the threshold frequency of the metal to detect Ultra Violet light will be higher than the threshold frequency of the metal to detect visible light.

Because the electrons in the cathode start out with an initial E_k of 0V (not moving) $\Delta E = E_{k2}$ $(\Delta E = E_{k2} - E_{k1})$

Find E_k usind $V = \frac{\Delta E}{q}$, $q = 1.60 \times 10^{-19}$ C (electron)

$\Delta E = E_k$ $\qquad V =$ use average max voltage separately for metal X & Y.

Once E_k for both metal x and metal y is calculated, solve for the threshold frequency of each metal (f_0)

$E_k = hf - W$ where $W = hf_0$ $\qquad h = 6.63 \times 10^{-34}$ Js
$f =$ average min. freq. from chart.

f_0 for metal x = ______

f_0 for metal y = ______

The metal with the higher threshold frequency is used to detect ultra violet light and the metal with the lower threshold frequency is used to detect visible light.

EXPERIMENT (THRESHOLD FREQUENCY)

Purpose: To correctly identify and label the cathode ray tubes containing metal x and metal y according to the EMR it detects: either visible or ultraviolet.

Materials: cathode ray tubes containg metal x and metal y.
variable frequency electromagnetic wave source
variable voltage source
volt meter
dark room
ammeter (if available)

Procedure:
1. Set up the apparatus shown in the diagram in a darkroom.
2. Turn on the power supply so that a cathode ray can be seen between the cathode and the anode
3. Slowly reduce the voltage until the current is 0A. but there is still an electric potential difference on the cathode. Record the voltage at which this occurs (If an ammeter isn't available, wait until no cathode ray can be seen.)
4. Using the variable-frequency electromagnetic wave source, shine incident light on Metal x with the lowest possible frequency.
5. Slowly increase the frequency of the incident light until a current can be detected by the ammeter. Record the frequency of the incident light at which this occurs.
6. Repeat steps #2-5 with metal x 5-10 times so that there is minimal experimental error.
7. Now follow steps 2-6 with metal y.

Observations: In the table [on the next page] record the max. voltage at which no current was detected (step 3) and the min. frequency at which a current was detected (step 5). The average for these values can be found by adding the values and dividing by the # of values.

	Metal X		Metal Y	
Trial #	Max V	Min f	Max V	Min f
1 2 ⋮ 10				

Content	3 × 2 =	6
Communication		3
		$\frac{9}{11}$

Student Sample Three

Communication Score—2

Rationale: The response is well organized; however, it fails to address the requirement of using either a calculation or a derived algebraic expression. Incomplete answers cannot be awarded full communication marks.

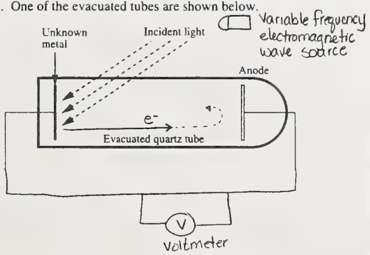
Content Score—2

Rationale: The response identifies a procedure that reflects a partial understanding of the photoelectric effect. It does not directly address the concept of threshold frequency, which must be inferred from the procedure. The setup, as shown in the diagram, is unlikely to provide the measurements needed to support the analysis.

Written Response – 11 marks

Use the following information to answer written-response question 2.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes are shown below.



Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

Purpose: Which of the two metals is metal x and which is metal y ?

Equipment: evacuated tube containing metal x
evacuated tube containing metal y
variable-frequency electromagnetic wave source
~~variable voltage source~~
volt meter

Procedure:
1. connect apparatus as shown in the diagram to the left.
2. turn on the variable-frequency electromagnetic wave source to the frequency of visible light. Turn up the frequency until there is a reading on the voltmeter.
3. record the frequency
4. if there is no reading in the visible light range, increase the frequency of the variable frequency electromagnetic wave source slowly until there is a reading on the voltmeter. Measure and record the frequency.

DATA:

	ν (Hz)	$V_{reading}$ (Yes/No)
Tube 1	visible light	N.
Tube 2	visible light	Y
Tube 1	UV light	Y
Tube 2	UV light	Y

Analysis: Tube 2 (not Tube1) responded to visible light.
Tube 1 (and Tube 2) responded to U.V. light.

Conclusion: Tube 2 contains metal x. Tube1 contains metal y. We know this because Tube2 only responded to visible light.

Content	2 × 2 = 4
Communication	2
	$\frac{6}{11}$

Student Sample Four

Communication Score—1

Rationale: The response is incomplete and somewhat unclear. There is an attempt to describe an experimental design, but little or no detail is provided. There is a general misuse of physics vocabulary and a very weak relationship between the experiment and the diagram.

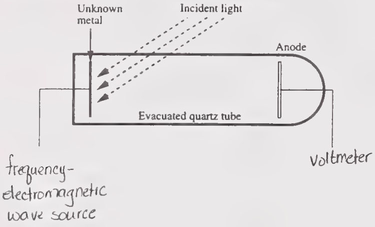
Content Score—1

Rationale: The response contains a statement of purpose, list of equipment, and a procedure. However, although the procedure uses the term “threshold frequency,” it indicates a very poor understanding of the photoelectric effect. There are no measurements indicated. Finally, the response provides no analysis in order to distinguish between the metals.

Written Response – 11 marks

Use the following information to answer written-response question 2.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes are shown below.



Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

First of all, the Photoelectric Effect occurs when electrons are emitted immediately after coming into contact with a metal surface. But in order for the electrons to even be emitted, a threshold frequency must be met.

Purpose: To determine metal X and metal Y in two evacuated tubes, using the photoelectric effect.

Materials:
- Voltmeter
- variable voltage source
- frequency - electromagnetic wave source
- Anode
- Evacuated Quartz tube
- 2 unknown metals
- incident light

Procedure:
The threshold frequency of each metal needs to be met, so shine the incident light onto the unknown metals. This will need various tries. Keep increasing the light source while measuring the frequency with the variable frequency - electromagnetic wave source. Eventually the threshold frequency will be met on both metals and from there, we can calculate and determine which metal is which.

Content 1 × 2 = 2
Communication 1

$$\frac{3}{11}$$

Student Sample Five

Communication Score—1

Rationale: The response is incomplete and somewhat unclear. There is an attempt to describe an experimental design, but little or no detail is provided. There is a general misuse of physics vocabulary and a weak relationship between the experiment and the diagram.

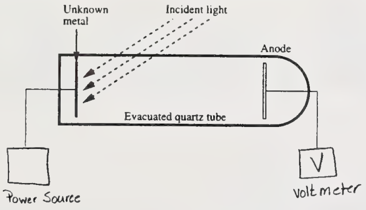
Content Score—0

Rationale: The response contains a statement of purpose, list of equipment, and a procedure; however, the procedure indicates little or no understanding of the photoelectric effect. The response incorrectly identifies measurements to be made and provides no analysis.

Written Response – 11 marks

Use the following information to answer written-response question 2.

The labels have fallen off two evacuated tubes that have unknown metals at each cathode. One tube, with Metal X as its cathode, detects visible light leakage from cameras. The other tube, with Metal Y as its cathode, detects ultraviolet leakage from shielded equipment. A student needs to know which tube is which. One of the evacuated tubes are shown below.



Also available is a variable-frequency electromagnetic wave source, a variable voltage source, a voltmeter, and any reference tables needed.

Purpose: to determine what Metal X and Metal Y are and the difference between the 2 tubes.

Materials:
- cathode tubes
- voltmeter
- power source
- electromagnetic wave source

Procedure:
- shine different coloured lights upon the tubes until there is a voltmeter reading fluctuation

Measurements:
- volt readings
- power input readings

Analyze what has happened when the different coloured light is shone upon the tube.

The different wavelengths will correspond to different wavelengths of the metal distinguishing them.

Content	0 × 2 = 0
Communication	1
	1/11

Appendix A

Calculator Policy

POLICY: USE OF CALCULATORS ON ALBERTA EDUCATION DIPLOMA EXAMINATIONS

Rationale
The knowledge, skills, and attitudes relevant to technology and its uses are being incorporated into courses and programs of study wherever appropriate. Students are expected to learn the advantages and limitations of technology developments and their impact upon society. The ability to use technology helps students understand and appreciate the process of technological change, gives added depth to programs, and provides the basis for the development of skills and understanding. These expectations are reflected in the diploma examination. Since the data provided for writing diploma examinations in mathematics and the sciences do not include information such as logarithms and trigonometric functions, students will need to use scientific calculators for these exams.

Definition
This policy considers a scientific calculator to be a hand-held device designed primarily for mathematical computations. Included in this definition are those scientific calculators having graphing capabilities, built-in formulas, mathematical functions, or other programmable features.

Policy
To ensure compatibility with provincial *Programs of Study* and equity and fairness to all students, Alberta Education expects students to use scientific calculators, as defined above, when they are writing diploma examinations in mathematics and the sciences. Examinations are constructed to ensure that the use of particular models of calculators neither advantages nor disadvantages individual students.

Procedures

1. Teachers must, at the beginning of a course, advise students of the types of calculators that they may use when writing diploma examinations in mathematics and the sciences. Teachers must also advise students of the types of information that can be stored in calculators that are brought into diploma examinations. Calculators that have built-in notes (definitions or explanations in alpha notation) that cannot be cleared are not permitted.

2. Students must clear calculators that are brought into diploma examinations of all information that they have stored except for
    a. programs used for computing values of the formulas on the diploma examination data tear-out pages or in the data booklets
    b. programs used for graphing quadratic relations as found in the Mathematics 30/33 Interim Teacher Resource Manual

3. Students must not bring external devices to support calculators into the exam. Such devices include manuals, printed or electronic cards, printers, memory expansion chips or cards, external keyboards, or any annotations outline operational procedures for scientific calculators.

4. In preparation for calculator failure, students may bring extra calculators and batteries into the exam room.

5. During exams, supervising teachers must ensure that
    a. all calculators operate in silent mode
    b. students do not share calculators or information contained within them
    c. calculator cases are stored on the floor throughout the exam
    d. all examination rules are followed

6. If you have any questions or comments about the implementation of this policy, please contact the Math/Science Unit, Student Evaluation Branch, at 403-427-0010 or FAX 403-422-4200.

Appendix B

Guidelines for Significant Digits, Manipulation of Data, and Rounding in the Science Diploma Examinations

Significant Digits (measured values)

1. For all non-logarithmic values, regardless of decimal position, any of the digits 1 to 9 is a significant digit; 0 may be significant. For example:

   123 0.123 0.00230 2.30×10^3
   all have 3 significant digits

2. Leading zeros are not significant. For example:

   0.12 and 0.012 each have two significant digits

3. Trailing zeros to the right of the decimal are significant. For example:

   0.123 00 and 20.000 each have five significant digits

4. Zeros to the right of a whole number are considered to be ambiguous. **The Student Evaluation Branch considers all trailing zeros to be significant**. For example:

   200 has three significant digits

5. For logarithmic values, such as pH, any digit to the left of the decimal is **not** significant. For example:

   a pH of 1.23 has two significant digits
   a pH of 7 has no significant digits

Manipulation of Data

1. When adding or subtracting measured quantities, the calculated answer should be rounded to the same degree of precision as that of the least precise number used in the computation **if this is the only operation**. For example:

   $$\begin{array}{rl} 12.3 & \text{(least precise)} \\ 0.12 & \\ \underline{12.34} & \\ 24.76 & \end{array}$$

   The answer should be rounded to 24.8.

2. When multiplying or dividing measured quantities, the calculated answer should be rounded to the same number of significant digits as are contained in the quantity with the fewest number of significant digits **if this is the only operation**. For example:

   (1.23)(54.321) = 66.81483

   The answer should be rounded to 66.8.

3. **When a series of calculations is performed, each interim value should not be rounded before carrying out the next calculation.** The final answer should then be rounded to the same number of significant digits as are contained in the quantity in the original data with the fewest number of significant digits. For example:

   In determining the value of (1.23)(4.321)/(3.45 – 3.21), three calculations are required:

   a. 3.45 – 3.21 = 0.24

   b. (1.23)(4.321) = 5.31483

   c. 5.31483/0.24 = 22.145125

      [Not 5.31/0.24 = 22.125]

   The value should be rounded to 22.1.

   Note: In the example given, steps *a* and *b* yield interim values. These values should not be used in determining the number of significant digits.

4. When calculations involve exact numbers (counted and defined values), the calculated answer should be rounded based upon the measured value(s). For example:

   12 eggs × 52.3 g/egg = 628 g

Rounding

1. When the first digit to be dropped is less than or equal to 4, the last digit retained should not be changed. For example:

   1.2345 rounded to three digits is 1.23

2. When the first digit to be dropped is greater than or equal to 5, the last digit retained should be increased by one. For example:

   12.25 rounded to three digits is 12.3

Appendix C

Directing Words

Discuss

The word “discuss” will not be used as a directing word on math and science diploma examinations because it is not used consistently to mean a single activity

The following words are specific in meaning.

Compare

Examine the character or qualities of two things by providing characteristics of both that point out their mutual *similarities* and *differences*

Conclude

State a logical end based on reasoning and/or evidence

Contrast/Distinguish

Point out the *differences* between two things that have similar or comparable natures

Criticize

Point out the *merits* and *demerits* of an item or issue

Define

Provide the essential qualities or meaning of a word or concept; make distinct and clear by marking out the limits

Describe

Give a written account or represent the characteristics of something by a figure, model, or picture

Design/Plan

Construct a plan, i.e., a detailed sequence of actions, for a specific purpose

Enumerate

Specify one by one or list in concise form and according to some order

Evaluate

Give the significance or worth of something by identifying the good and bad points or the advantages and disadvantages

Explain

Make clear what is not immediately obvious or entirely known; give the cause of or reason for; make known in detail

How

Show in what manner or way, with what meaning

Hypothesize

Form a tentative proposition intended as a possible explanation for an observed phenomenon; i.e., a possible cause for a specific effect. The proposition should be testable logically and/or empirically

Identify

Recognize and select as having the characteristics of something

Illustrate

Make clear by giving an example. The form of the example must be specified in the question; i.e., word description, sketch, or diagram

Infer

Form a generalization from sample data; arrive at a conclusion by reasoning from evidence

Interpret

Tell the meaning of something, present information in a new form that adds meaning to the original data

Justify/Show How

Show reasons for or give facts that support a position

Outline

Give, in an organized fashion, the essential parts of something. The form of the outline must be specified in the question; i.e., lists, flow charts, concept maps

Predict

Tell in advance on the basis of empirical evidence and/or logic

Prove

Establish the truth, validity, or genuineness of something by giving factual evidence or logical reasons

Relate

Show logical or causal connection between things

Solve

Give a solution for a problem; i.e., explanation in words and/or numbers

Summarize

Give a brief account of the main points

Trace

Give a step-by-step description of the development

Why

Show the cause, reason, or purpose

Appendix D

Science Process Words

Hypothesis: A single proposition intended as a possible explanation for an observed phenomenon; e.g., a possible cause for a specific effect

Conclusion: A proposition that summarizes the extent to which a hypothesis and/or a theory has been supported or contradicted by the evidence

Experiment: A set of manipulations and/or specific observations of nature that allow the testing of hypotheses and/or generalizations

Variables: Conditions that can change in an experiment. Variables in experiments are categorized as:

- *manipulated variables* (independent variables)—conditions that were deliberately changed by the experimenter
- *controlled variables* (fixed or restrained variables) —conditions that could have changed but did not, because of the intervention of the experimenter
- *responding variables* (dependent variables)—conditions that changed in response to the change in the manipulated variables

Technology: The development of our understanding of science is directly related to the development of technology. The meaning of technology has many facets, but in general, technology refers to a way of doing something. This includes the development of tools and new techniques for solving problems. It also includes ideas and their organization for achieving practical purposes. In the context of an examination question, technology includes both these facets of meaning. That is, a technological explanation should include not only identification and descriptions of equipment (tools, products) but also explanations of procedures.

Appendix E

Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IA	IIA	IIIB	IVB	VB	VIB	VIIB		VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA or O
1 H 1.01 hydrogen																	2 He 4.00 helium
3 Li 6.94 lithium	4 Be 9.01 beryllium											5 B 10.81 boron	6 C 12.01 carbon	7 N 14.01 nitrogen	8 O 16.00 oxygen	9 F 19.00 fluorine	10 Ne 20.17 neon
11 Na 22.99 sodium	12 Mg 24.31 magnesium											13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.06 sulphur	17 Cl 35.45 chlorine	18 Ar 39.95 argon
19 K 39.10 potassium	20 Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.90 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.71 nickel	29 Cu 63.55 copper	30 Zn 65.38 zinc	31 Ga 69.72 gallium	32 Ge 72.59 germanium	33 As 74.92 arsenic	34 Se 78.96 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton
37 Rb 85.47 rubidium	38 Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.94 molybdenum	43 Tc (98.91) technetium	44 Ru 101.07 ruthenium	45 Rh 102.91 rhodium	46 Pd 106.40 palladium	47 Ag 107.87 silver	48 Cd 112.41 cadmium	49 In 114.82 indium	50 Sn 118.69 tin	51 Sb 121.75 antimony	52 Te 127.60 tellurium	53 I 126.90 iodine	54 Xe 131.30 xenon
55 Cs 132.91 cesium	56 Ba 137.33 barium	57-71	72 Hf 178.49 hafnium	73 Ta 180.95 tantalum	74 W 183.85 tungsten	75 Re 186.21 rhenium	76 Os 190.20 osmium	77 Ir 192.22 iridium	78 Pt 195.09 platinum	79 Au 196.97 gold	80 Hg 200.59 mercury	81 Tl 204.37 thallium	82 Pb 207.19 lead	83 Bi 208.98 bismuth	84 Po (208.98) polonium	85 At (209.98) astatine	86 Rn (222.02) radon
87 Fr (223.02) francium	88 Ra (226.03) radium	89-103	104 Unq (266.11) unnilquadium	105 Unp (262.11) unnilpentium	106 Unh (263.12) unnilhexium	107 Uns (262.12) unnilseptium	108 Uno (265) unniloctium	109 Une (266) unnilennium									
			57 La 138.91 lanthanum	58 Ce 140.12 cerium	59 Pr 140.91 praseodymium	60 Nd 144.24 neodymium	61 Pm (144.91) promethium	62 Sm 150.35 samarium	63 Eu 151.96 europium	64 Gd 157.25 gadolinium	65 Tb 158.93 terbium	66 Dy 162.50 dysprosium	67 Ho 164.93 holmium	68 Er 167.26 erbium	69 Tm 168.93 thulium	70 Yb 173.04 ytterbium	71 Lu 174.97 lutetium
			89 Ac (277.03) actinium	90 Th (232.04) thorium	91 Pa (231.04) protactinium	92 U 238.03 uranium	93 Np (237.05) neptunium	94 Pu (244.06) plutonium	95 Am (243.06) americium	96 Cm (247.07) curium	97 Bk (247.07) berkelium	98 Cf (242.06) californium	99 Es (252.08) einsteinium	100 Fm (257.10) fermium	101 Md (258.10) mendelevium	102 No (259.10) nobelium	103 Lr (260.11) lawrencium

Key

Atomic number →	3
Symbol ←	Li
Atomic molar mass →	6.94
Name →	lithium

Based on $^{12}_{6}C$

( ) Indicates mass of the most stable isotope

PHYSICS DATA SHEETS

CONSTANTS

Gravity, Electricity, and Magnetism

Acceleration Due to Gravity **or** Gravitational Field Near Earth	a_g or $g = 9.81\ \text{m/s}^2$ or $9.81\ \text{N/kg}$
Gravitational Constant	$G = 6.67 \times 10^{-11}\ \text{N•m}^2/\text{kg}^2$
Mass of Earth	$M_e = 5.98 \times 10^{24}\ \text{kg}$
Radius of Earth	$R_e = 6.37 \times 10^{6}\ \text{m}$
Coulomb's Law Constant	$k = 8.99 \times 10^{9}\ \text{N•m}^2/\text{C}^2$
Electron Volt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$
Elementary Charge	$e = 1.60 \times 10^{-19}\ \text{C}$
Index of Refraction of Air	$n = 1.00$
Speed of Light in Vacuum	$c = 3.00 \times 10^{8}\ \text{m/s}$

Atomic Physics

Energy of an Electron in the 1st Bohr Orbit of Hydrogen	$E_1 = -2.18 \times 10^{-18}\ \text{J}$ or $-13.6\ \text{eV}$
Planck's Constant	$h = 6.63 \times 10^{-34}\ \text{J•s}$ or $4.14 \times 10^{-15}\ \text{eV•s}$
Radius of 1st Bohr Orbit of Hydrogen	$r_1 = 5.29 \times 10^{-11}\ \text{m}$
Rydberg's Constant for Hydrogen	$R_H = 1.10 \times 10^{7}/\text{m}$

Particles

	Rest Mass	Charge
Alpha Particle	$m_\alpha = 6.65 \times 10^{-27}\ \text{kg}$	α^{2+}
Electron	$m_e = 9.11 \times 10^{-31}\ \text{kg}$	e^-
Neutron	$m_n = 1.67 \times 10^{-27}\ \text{kg}$	n^0
Proton	$m_p = 1.67 \times 10^{-27}\ \text{kg}$	p^+

Trigonometry and Vectors

$$\sin\theta = \frac{opposite}{hypotenuse}$$

$$\cos\theta = \frac{adjacent}{hypotenuse}$$

$$\tan\theta = \frac{opposite}{adjacent}$$

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

$$c^2 = a^2 + b^2 - 2ab\cos C$$

For any Vector $\vec{R}$

$$R = \sqrt{R_x^{\ 2} + R_y^{\ 2}}$$

$$\tan\theta = \frac{R_y}{R_x}$$

$$R_x = R\cos\theta$$

$$R_y = R\sin\theta$$

Prefixes Used With SI Units

Prefix	Symbol	Exponential Value	Prefix	Symbol	Exponential Value
pico	p	10^{-12}	tera	T	10^{12}
nano	n	10^{-9}	giga	G	10^{9}
micro	µ	10^{-6}	mega	M	10^{6}
milli	m	10^{-3}	kilo	k	10^{3}
centi	c	10^{-2}	hecto	h	10^{2}
deci	d	10^{-1}	deka	da	10^{1}

EQUATIONS

Kinematics

$$\vec{v}_{\mathrm{ave}} = \frac{\vec{d}}{t}$$

$$\vec{d} = \vec{v}_{\mathrm{f}}t - \frac{1}{2}\vec{a}t^2$$

$$\vec{a} = \frac{\vec{v}_{\mathrm{f}} - \vec{v}_{\mathrm{i}}}{t}$$

$$\vec{d} = \left(\frac{\vec{v}_{\mathrm{f}} + \vec{v}_{\mathrm{i}}}{2}\right)t$$

$$\vec{d} = \vec{v}_{\mathrm{i}}t + \frac{1}{2}\vec{a}t^2$$

$$v_{\mathrm{f}}^2 = v_{\mathrm{i}}^2 + 2ad$$

$$v = \frac{2\pi r}{T}$$

$$a = \frac{v^2}{r}$$

Dynamics

$$\vec{F} = m\vec{a}$$

$$F_{\mathrm{g}} = \frac{Gm_1m_2}{r^2}$$

$$\vec{F}\Delta t = m\Delta\vec{v}$$

$$g = \frac{Gm_1}{r^2}$$

$$\vec{F}_{\mathrm{g}} = m\vec{g}$$

$$F_{\mathrm{c}} = \frac{mv^2}{r}$$

$$F_{\mathrm{f}} = \mu F_{\mathrm{N}}$$

$$F_{\mathrm{c}} = \frac{4\pi^2 mr}{T^2}$$

$$\vec{F}_{\mathrm{s}} = -k\vec{x}$$

Momentum and Energy

$$\vec{p} = m\vec{v}$$

$$E_{\mathrm{k}} = \frac{1}{2}mv^2$$

$$W = Fd$$

$$W = \Delta E = Fd\cos\theta$$

$$E_{\mathrm{p}} = mgh$$

$$P = \frac{W}{t} = \frac{\Delta E}{t}$$

$$E_{\mathrm{p}} = \frac{1}{2}kx^2$$

Waves and Light

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$\lambda = \frac{xd}{nl}$$

$$T = \frac{1}{f}$$

$$\lambda = \frac{d\sin\theta}{n}$$

$$v = f\lambda$$

$$m = \frac{h_{\mathrm{i}}}{h_0} = \frac{-d_{\mathrm{i}}}{d_0}$$

$$\frac{\lambda_1}{2} = l;\ \frac{\lambda_1}{4} = l$$

$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_{\mathrm{i}}}$$

Atomic Physics

$$hf = E_{\mathrm{k}_{\mathrm{max}}} + W$$

$$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{n_{\mathrm{f}}^2} - \frac{1}{n_{\mathrm{i}}^2}\right)$$

$$W = hf_0$$

$$E_{\mathrm{n}} = \frac{1}{n^2}E_1$$

$$E_{\mathrm{k}_{\mathrm{max}}} = qV_{\mathrm{stop}}$$

$$r_{\mathrm{n}} = n^2 r_1$$

$$E = hf = \frac{hc}{\lambda}$$

$$N = N_0\left(\frac{1}{2}\right)^n$$

Quantum Mechanics and Nuclear Physics

$$E = mc^2$$

$$p = \frac{h}{\lambda}$$

$$p = \frac{hf}{c};\ E = pc$$

Electricity and Magnetism

$$F_{\mathrm{e}} = \frac{kq_1q_2}{r^2}$$

$$V = IR$$

$$|\vec{E}| = \frac{kq_1}{r^2}$$

$$P = IV$$

$$\vec{E} = \frac{\vec{F}_{\mathrm{e}}}{q}$$

$$I = \frac{q}{t}$$

$$|\vec{E}| = \frac{V}{d}$$

$$F_{\mathrm{m}} = IlB_{\perp}$$

$$V = \frac{\Delta E}{q}$$

$$F_{\mathrm{m}} = qvB_{\perp}$$

$$R = R_1 + R_2 + R_3$$

$$V = lvB_{\perp}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{N_{\mathrm{p}}}{N_{\mathrm{s}}} = \frac{V_{\mathrm{p}}}{V_{\mathrm{s}}} = \frac{I_{\mathrm{s}}}{I_{\mathrm{p}}}$$

$$I_{\mathrm{eff}} = 0.707\ I_{\mathrm{max}}$$

$$V_{\mathrm{eff}} = 0.707\ V_{\mathrm{max}}$$

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